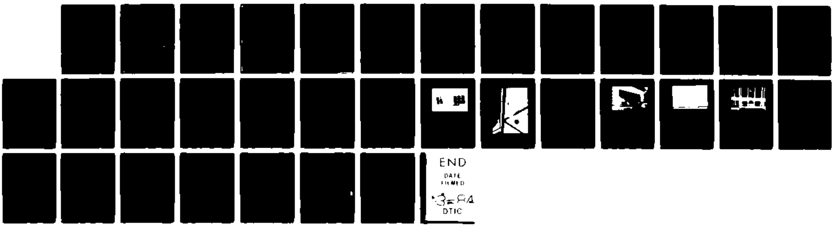
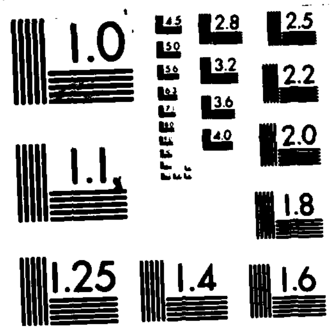
AD-A138 496 DESIGN GUIDELINES FOR HEATING AIRCRAFT HANGARS WITH RADIANT HEATERS(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA E L CORREA DEC 83 NCEL-TN-1684 1/1

UNCLASSIFIED F/G 13/1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12)

ADA138496

TN NO: N-1684

TITLE: DESIGN GUIDELINES FOR HEATING AIRCRAFT HANGARS WITH RADIANT HEATERS

AUTHOR: Edward L. Correa

DATE: December 1983

SPONSOR: Naval Material Command

PROGRAM NO: Z0829-01-111C

TECHNICAL NOTE

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

Approved for public release; distribution unlimited

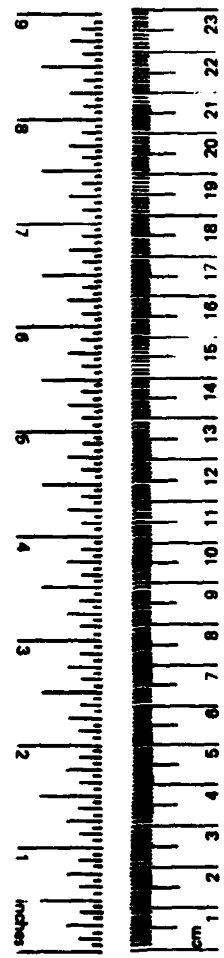
84 02 29 005

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

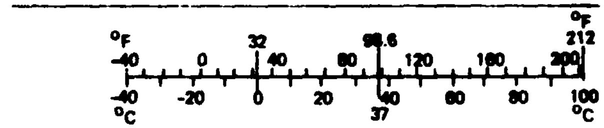
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD-A138496

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TN-1684	2. GOVT ACCESSION NO.: DN687061
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): DESIGN GUIDELINES FOR HEATING AIRCRAFT HANGARS WITH RADIANT HEATERS	5. TYPE OF REPORT & PERIOD COVERED: Not final; Oct 1982 – Sep 1983
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Edward L. Correa	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: NAVAL CIVIL ENGINEERING LABORATORY, Port Hueneme, CA 93043	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: PE 63724N, Z0829-01-111C
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Material Command, Washington, DC 20360	12. REPORT DATE: December 1983
	13. NUMBER OF PAGES: 26
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Energy conservation, infrared heating, HVAC, hangars, radiant heating

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An investigation was conducted on the use of radiant heaters to reduce the cost of heating aircraft hangars. Those best suited for space heating aircraft hangars were found to be the gas-fired, high-intensity, porous, refractory infrared heaters. Radiant heaters provide increased thermal comfort for personnel while substantially reducing heating costs. Considerable fuel is saved by: (1) allowing a lower interior air temperature to be maintained while providing personnel comfort, (2) reducing heat stratification, (3) reducing fuel consumption with high

(continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Continued

efficiency burners, (4) reducing building heat loss, and (5) heating only occupied areas rather than the whole building. This report includes the principles of radiant heating in hangars, guidelines for optimum system design, and discussion of the physiological aspects of radiant heating. Cost analysis procedures are given for determining the cost-effectiveness of the radiant systems for comparison with other types of heating systems.

Library Card

Naval Civil Engineering Laboratory
DESIGN GUIDELINES FOR HEATING AIRCRAFT HANGARS WITH RADIANT HEATERS (Not final), by Edward L. Correa
TN-1684 26 pp illus December 1983 Unclassified

1. Energy conservation 2. Infrared heating I. Z0829-01-111C

An investigation was conducted on the use of radiant heaters to reduce the cost of heating aircraft hangars. Those best suited for space heating aircraft hangars were found to be the gas-fired, high-intensity, porous, refractory infrared heaters. Radiant heaters provide increased thermal comfort for personnel while substantially reducing heating costs. Considerable fuel is saved by: (1) allowing a lower interior air temperature to be maintained while providing personnel comfort, (2) reducing heat stratification, (3) reducing fuel consumption with high efficiency burners, (4) reducing building heat loss, and (5) heating only occupied areas rather than the whole building. This report includes the principles of radiant heating in hangars, guidelines for optimum system design, and discussion of the physiological aspects of radiant heating. Cost analysis procedures are given for determining the cost-effectiveness of the radiant systems for comparison with other types of heating systems.

CONTENTS

INTRODUCTION

Over the past several years, costs for space heating large open bay buildings (e.g., aircraft hangars, warehouses) have increased with the rise in costs for energy. In addition, forced-air convective heaters currently in use can cause heat stratification and air stagnation. Stratification results in air temperatures being high near the ceiling but low at the floor level, resulting in thermal discomfort for personnel. Long periods of time are needed for heat recovery because the hangar air volume must be reheated when the main doors are opened to the cold outside air.

The Naval Civil Engineering Laboratory (NCEL) evaluated the use of radiant heaters in aircraft hangars as part of a Navy hangar heating investigation.

Presented in this report are the principles of radiant heating in aircraft hangars, guidelines for optimum system design, and information on the physiological aspects of radiant heating. Comparative cost analysis procedures are included for evaluating the cost-effectiveness of radiant heating systems with other types of heating systems. The report also presents information on what measures must be taken to comply with the National Fire Protection Association (NFPA) codes.

BACKGROUND

Aircraft hangars, because of their large open interiors, have always been difficult to space heat during the winter months because of heat stratification, slow heat recovery, and high heating costs. When forced-air convective heaters are used, the warm air rises, resulting in high air temperatures near the ceiling and lower temperatures at the floor level. In addition, when the main doors are opened, heated air is lost to the colder outside environment. Once the doors are closed, the heating process must start all over again.

CONVECTIVE HEATING

Convective heaters are suitable for moderately low ceiling applications where the heated air maintains a reasonably uniform temperature throughout the room. As the ceiling height increases, however, convective heaters become inefficient in maintaining thermal comfort temperatures at floor levels. Natural convection forces the warm air to rise to the ceiling - away from the floor level where it is needed.

In buildings such as aircraft hangars, once the air is heated it is difficult to keep it at floor level. As the warm air rises, more heated air must be produced to replace it. As this cycle continues, more heated air collects at the ceiling, resulting in higher temperatures in that area. The higher temperatures increase the heat loss through the upper walls and roof surfaces. Thermal comfort at the floor level is achieved at the expense of heating the overhead spaces. The rising hot air also causes a "stack effect" which increases air infiltration, another major source of hangar heat loss.

PRINCIPLES OF RADIANT HEATING

Radiant heaters (Figure 1) are best applied where and when convective heaters are less than satisfactory. Radiant heaters radiate heat in the form of infrared (IR) waves in a straight, line-of-sight direction that makes them impractical for applications below 8 feet in height because of uneven heat distribution. Areas shaded from the radiant heat do not receive the same heat flux density as exposed areas.

Air, the medium for convective heat, is a poor absorber of IR radiation; like light energy, IR radiation is transmitted in the form of invisible electromagnetic radiation. Upon striking an absorbing mass, IR radiant energy is converted into heat, and this absorptive mass (e.g., concrete floor) becomes a reservoir of heat storage. Once the floor temperature is greater than the interior ambient air temperature this heat reservoir gives off heat to the surrounding environment by convection, conduction, and radiation. Quick heat recoveries are possible because the hangar is heated from the floor up rather than from the ceiling down, as is the case with convective heaters.

The performance of a radiant heater depends upon the emissivity of the heater's emitter surface and the absorptivity of the receiver surface. The emissivity of the emitter determines the output efficiency of the emitter while the absorptivity of the receiver determines at what efficiency the heat is being absorbed. For any given material at thermal equilibrium, the emissivity and absorptivity factors are the same, and either surface factor is determined on a scale from 0 to 1.00 where 0 means no emission of any IR radiation and 1.00 means emission of all its radiation. Realistically, neither can be achieved. For an opaque material, reflectivity is the complement absorptivity, as shown in Figure 2.

IR radiation is the primary mode of heat transmission; all matter, whether solid, liquid, or gas, above a temperature of absolute zero emits IR radiation.

The emmitter's surface temperature determines the wavelength and intensity of the radiant energy: the higher the surface temperature, the shorter the wavelength and the greater the intensity. The intensity q, or rate of heat transfer, is directly proportional to the fourth power of the surface temperatures, as shown in Equation 1:

$$q = K \varepsilon A T^4 \qquad \text{(Btu/hr)} \qquad (1)$$

where: q = rate of IR emission or emissive power (Btu/hr)

$K = 0.173 \times 10^{-8}$ Btu/hr ft^2°R^4 (Stephan-Boltzman constant)

ε = emissivity of the emitter surface (dimensionless)

A = surface area of the emitter (ft^2)

T = absolute temperature of the emitter surface (°R)

ADVANTAGES OF RADIANT HEATERS

A properly designed and installed radiant heating system can eliminate many of the heating problems associated with hangars. Radiant heaters achieve energy savings in a number of ways:

- Lower air temperatures for the same thermal comfort provided by convective heaters.

- Less building heat loss - Lower air temperatures reduce the quantity of heat transmitted through exterior building surfaces.

- Lower energy cost - The reduced building heat loss results in less fuel required for heating.

- Less air stratification and air infiltration - Lower air temperatures reduce heat stratification and air stagnation at the upper levels. The reduced temperature difference between the inside and outside air reduces the air infiltration losses through gravity ventilation or stack effect.

- Zone heating - Zones can be heated independently for changing work requirements. Rather than heating the whole hangar, work areas may be fully heated while storage areas may be heated to just above the dew point or freezing temperatures. Unoccupied areas may be left unheated. Zone heating requires additional heaters and thermostat controls than whole building radiant heating, but the additional expense for heating flexibility should be cost-effective.

- Heat storage - The radiant energy striking the concrete floor is converted into heat energy, which is absorbed by the floor. The floor thus becomes a heat storage reservoir. In addition, since the floor surface heats more quickly than the ambient air temperature, the floor acts as a radiator and gives off heat. Even when the hangar doors are opened to the cold outside air, the radiant heaters continue to store heat in the floor. When the doors are closed again, this stored heat plus the direct heat from the IR radiant heaters enable the temperature at the floor level to recover quickly (15-20 minutes).

- Condensation/corrosion control - If humidity or condensation is a problem, radiant heaters can supply just enough heat to keep the floor or an object just above the dew point or freezing temperature. This helps eliminate unwanted moisture and corrosion problems.

DESIGNING A RADIANT HEATING SYSTEM

Several factors must be carefully considered when a radiant heating system is being designed for any building. As indicated earlier, a properly designed and installed heating system in an aircraft hangar can eliminate many operational and cost problems for the hangar manager.

Emissivities

The critical factor in designing an efficient radiant heating system is to match the emissivity of the radiant heater to the absorptivity of the objects to be heated (i.e., personnel, concrete floors, or other items). The emissivity of a material may vary under different temperatures and IR wavelengths. For example, the emissivity of white paint is approximately 0.18 (18% absorptance) for a solar light IR wavelength of 0.6 micron and 0.95 (95% absorptance) for IR radiation of 9.3 microns at 100°F. Appendix A in Reference 1 has a list of emissivities for building materials exposed to various heat temperatures and wavelengths. To maximize the thermal efficiency of a radiant heating system, radiant heaters need to emit IR energy in the range that the objects to be heated will most readily absorb.

National Fire Protection Association Codes

The purpose of the NFPA regulations are to insure that the heaters are safely installed and will not create a hazard or interfere with the existing fire protection systems.

Volume 10 of Reference 2 indicates that heaters employing an open flame or glowing element that are listed for use in aircraft hangars may be installed if they meet the spacing requirements in that chapter. Further information on installation requirements for IR radiant heaters can be found in the NFPA Codes listed below:

- Heaters/heating equipment/heating systems

  Volume 10: NFPA 409-1979 Aircraft Hangars, Chapter 9, Hangar Services and Utilities (Ref 2)

  Volume 9: NFPA 90A-1978 Standard on Installation of Air Conditioning and Ventilating Systems (Ref 3)

Volume 3: NFPA 31-1978 Installation of Oil Burning Equipment (Ref 4)

Volume 4: NFPA 54-1974 National Fuel Gas Code Parts I & II (Ref 5)

- Ventilation/blower/exhaust systems

  Volume 9: NFPA 90A-1978 (Ref 3)

  Volume 10: NFPA 409-1979, and Chapter 6, Section 6-7.32, Mechanical Ventilation (Ref 2)

  Volume 9: NFPA 91-1973 Standard for the Installation of Blower and Exhaust Systems (Ref 6)

- Electrical Systems

  Volume 6: NFPA 70-1978 National Electrical Code, Article 513, Aircraft Hangars (Ref 7)

Clearances

Radiant heaters will most likely be suspended from the ceiling or roof structural numbers to avoid contact with moving cranes or aircraft with high tail sections. These heaters cannot be installed above fire detection or sprinkler systems as the heat may be sufficient to activate these systems. Also, if the units are to be suspended among the roof structural members, the path of the IR radiant heat must be unobstructed to the floor level. Structural members, wiring, pipes, and other items can be damaged. Figure 3 shows the damage that can occur when an IR radiant heater is installed just above a structural member; the intense heat charred the paint and exposed the metal to heat stress and corrosion.

Layout

Perimeter. A perimeter layout of radiant heaters such as that in Figure 4 will heat the hangar from the base of the wall to the center floor. The heaters should be oriented so that their field of coverage starts at the floor edge with the wall and continues toward the center (Figure 5). The walls should not be included in the heater's line-of-sight to minimize heat loss through the walls. If the hangar is extra large, an additional center row mounting may be necessary. Additional heaters will be required over the main hangar doors as shown in Figure 6 because of the larger heat loss when the doors are open.

Checkerboard. An overhead checkerboard layout would evenly disperse the heaters throughout the hangar (Figure 7). However, this layout would require more heaters than for the perimeter layout and would increase the network of piping and electrical wiring required for the heaters.

Venting

Venting is required for gas-fired radiant heaters. Building materials that are contiguous to the exterior (e.g., glass skylights) are potential collection points for condensation from warm moist air or from flue gases. If the outside temperature is below the dew point temperature, condensation can form and drip down on the floor below, which is unacceptable both for aircraft maintenance and personnel safety. Also, products of combustion from fuels with LPG and propane mixed in with natural gas may have a high sulfur content. When these are combined with water vapor, these products can form sulphuric acid. Venting of IR heaters will remove the combustion gases and prevent condensation.

Direct. Direct venting of the gas-fired radiant heaters will remove flue gases directly from the hangar through exhaust stacks in the roof (Figure 8). If such venting is used, these stacks should have dampers at the top to prevent downdrafts. These dampers prevent the IR burners from being "blown-out" by downdrafts and help eliminate the funneling of cold air down through the stack when the heaters are not in use. The exhaust stacks must rise directly from the IR radiant burners (Figure 9); a horizontal stack will impede the rise of hot flue gases. When two vent stacks are joined together, the diameter of the resulting stack must be sufficient to handle the combined flow rate from the feeding stacks. Also, the stack height above the roof must be sufficient to allow flue gases to mix with the outside atmosphere.

Exhaust. Another venting method is the use of exhaust fans with spring-loaded draft shutters installed in the ceiling (Figure 10). When the exhaust fans are operating, positive air pressure forces the draft shutters to open and exhaust the flue gases. When the exhaust fans are shut off, the positive pressure of the exhaust airflow decreases and is overcome by the force of the loaded spring on the draft shutters, forcing them closed, thus preventing both warm air from escaping and cold air downdrafts from entering. These exhaust fans can be controlled automatically either of two ways:

1. A relay switch can turn on the exhaust fan whenever the heater operates and can turn it off whenever the heater is turned off. A timed delay of several seconds or minutes can be included to delay the fan shutoff to ensure purging of the flue gases.

2. The on-off function of the fans can be automatically controlled by a humidity control device. That is, whenever the moisture content from the flue gases reaches the sensor's pre-set level, the humidity control automatically turns the exhaust fans on. Once the moisture content of the air drops below the lower pre-set moisture range, the exhaust fans shut off. These sensors could be placed at several points in the roof structural members.

A manual override switch included in the above circuits could be used to bypass the above two systems should the need arise (e.g., to vent smoke or odors).

Minimizing Building Air Leakage

When the air temperature inside a hangar exceeds the outside air temperature, the difference in the densities between warm and cold air can cause gravity ventilation (Figure 11). To minimize the effects of gravity ventilation, IR heater flue gas stacks or vents must have dampers which close when the unit is not operating.

Heater Ignition

Electronic glow coils or electronic spark ignition should be used to ignite the gas-fired burners. They are very reliable and provide additional safety to prevent an accumulation of gas fumes (such as when a pilot light gets blown out). These ignition systems have built-in safety features to shut down the gas supply if the spark fails to ignite the burner in a specified number of seconds. This safety feature prevents gas from flowing through the ceramic burner into the aircraft hangar. Elimination of pilot lights saves additional energy as well as the inconvenience of re-lighting pilot lights if they blow out.

Thermostats

Thermostatic controls should be shielded to prevent heat buildup in the controls that are installed below radiant heaters. Thermostats should be located outside the line-of-sight of the IR radiant energy.

Maintenance Access

Section 9-1.2.3 of Reference 2 states that access to suspended heaters shall be assured for recurrent maintenance. Though a truck with a hydraulic lift may fulfill this requirement, catwalks with an access ladder is a better alternative. Catwalks are more expensive initially, but will give immediate and assured access to heater units at any time and for any hangar floor configuration. With catwalks, the direction of the heater may be changed easily and at any time to meet changing heating requirements at the floor level.

Trucks with hydraulic lifts have access only when the floor space below is clear and only if there is a path to that floor space. If an aircraft is in the way, it may have to be removed or the maintenance may have to be rescheduled. The truck would require a minimum of two persons and whatever additional manpower necessary to relocate aircraft for the truck's access. With the truck, crew, and additional wingwalkers and aircraft tow vehicle, a simple inspection or maintenance repair can turn into a costly logistic problem requiring advanced scheduling. Also, changing floor arrangements in open bay buildings, such as the installation of a storage area or other fixed obstacles, can obstruct access to these overhead heaters.

Electric Solenoid Shutoff Valves

Installation of an electrical solenoid shutoff valve to each heater (Figure 12) is recommended to isolate each heater. With this installation, other units on the same line can be used while an isolated unit is awaiting maintenance. In another example, if a tall tail section of an aircraft is placed too close to a heater, the switch can be shut off to the affected heater temporarily to prevent heat damage to the aircraft. The shutoff switch can be located directly below the heater, at a central control point or at both locations.

Loss of one heater may not degrade a heating system, but the loss of several may degrade it if several units are on the same line and do not have separate shutoff solenoids. In addition, manual shutoff valves for each heater are required (NFPA regulations, Ref 2 through 7) for gas-fired units.

Certification by Manufacturer

A survey was conducted to determine the experience of engineering organizations (government and civilian) in designing radiant heating systems. The survey indicated knowledge of radiant heating system design is not widespread.

The contract for the installation of a radiant radiating system should specify that the blueprints for the system design must be reviewed by the product's manufacturer. The manufacturer should follow up with an on-site certification of the system. Though this may increase the installation cost slightly, it will help eliminate costly correction of design errors. Some examples of design errors in existing IR heating systems are:

- High intensity IR heaters installed just above roof structural members (Figure 3).
- Vent stacks installed horizontally (Figure 8) which can cause the flue gases to stagnate.
- Vent stacks installed without downdraft dampers, resulting in cold downdrafts.

Periodic Inspections

Pre-season and post-season inspections should be made as part of a preventive maintenance plan. These inspections will greatly reduce the maintenance and increase the reliability of the heating system. Access catwalks will facilitate conducting these inspections.

Prior to the heating season the system should be visually inspected and operationally checked out to insure that the units are functional. Dust, debris, spider webs, or bird nests that may have accumulated in the units over the summer months should be removed.

For the post-heating season the units should be secured for the summer months. The gas jets for gas-fired units should be wrapped with tape, cloth, or vinyl wrap to help prevent dust and debris from accumulating.

PHYSIOLOGICAL EFFECTS OF IR RADIATION ON PERSONNEL

Physiological concerns with use of IR radiant energy are those adverse effects that may damage eyes and skin of personnel.

The eye normally has two forms of protection from excessive exposure to IR radiation energy: (1) the iris naturally contracts and (2) photophobia or painful reaction to intense light occurs. However, the lens of the eye can focus concentrated IR radiant energy onto the retina. Damage to the eye in the form of cataracts and retinal burns can occur if the iris does not have enough time to contract and the intensity of the IR radiant energy is great enough (Ref 8). The eye does not have a circulatory system to act as a cooling system to dissipate heat quickly (Ref 9).

In various studies it has been shown that short wavelengths of IR energy in the range of 1.0 to 2.0 microns may cause cataracts of the eye after prolonged and intimate exposure, but this exposure must be close and for a prolonged period of time for the damage to occur. Eye damage does not occur at IR radiant energy wavelengths longer than 2.0 microns. Gas-fired IR radiant heaters emit energy in the range of 2.0 to 6.0 microns (Ref 8).

Studies by J. Hardy (Ref 10) show that skin absorption is sensitive to the wavelength of the IR radiation; the skin absorptance is variable in the range between 0.4 to 2.0 microns (Figure 13). For wavelengths from 2.5 to 20.0 microns the skin absorptance of IR radiant energy is approximately 97 to 99% (Ref 10). For IR wavelengths longer than 2.6 microns, the skin, regardless of color, is essentially a black body. IR radiant energy penetrates to between 0.0008 and 0.00012 inch beneath the skin surface and, thus, interacts directly with the nerve endings and small blood vessels. This interaction gives the sensation of warmth.

The skin is more sensitive to the longer IR wavelengths than the shorter IR wavelengths. Also, objects with high moisture content absorb longer (>2 microns) wavelength energy more readily and at a higher percentage. Thus, smaller amounts of longer IR wavelength energy are needed to produce a sensation of warmth.

In summary, no adverse health effects associated with IR radiant energy with wavelengths longer than 2.0 microns have been detected. The skin is more responsive to these longer wavelengths for heat absorptance and warmth sensation.

COMPARATIVE COST ANALYSIS

Before designing a radiant heating system, the designer should prepare a cost analysis on the existing heating system and any proposed IR radiant heating system. An estimate can then be made on the seasonal fuel cost for each system. Once these estimates are made, then a cost comparison can be made to determine if the payback period will justify the cost of retrofitting a building with an IR radiant heating system.

A total seasonal fuel cost can be estimated by using the degree-day method presented in the ASHRAE Handbook. This estimate is based upon average weather data collected for the locality:

$$AFCU = \frac{24(HL)(DD)}{E(T_i - T_d)C} \quad (2)$$

where: AFCU = annual fuel consumption units (units of fuel)

HL = calculated total building heat loss (Btu/hr)

E = heating system efficiency

T_i = inside design temperature (°F)

T_d = average winter outside air temperature (°F)

C = heating value per unit of fuel (Btu/unit of fuel)

DD = degree days

After the annual fuel consumption is calculated for each system, the projected annual savings can be used to determine the payback period of the retrofit.

$$AHC = AFCU \times \text{fuel cost/unit of fuel (annual heating cost)} \quad (3)$$

$$PCS = AHC_{\text{existing system}} - AHC_{IR} \quad (4)$$

$$PBP = \frac{\text{Installation Cost of IR}}{PCS} \quad (5)$$

where: PCS = projected cost savings for fuel per year ($/yr)

PBP = pay back period

CONCLUSIONS

The results of this investigation indicate that radiant heaters are practical heaters for use in large open bay buildings. Generally, radiant heaters surpass convective forced-air counterparts in heating large open bays in the following ways:

- by providing increased thermal comfort at the floor level while substantially reducing heating costs and heat stagnation
- by being able to heat objects to just above the dew point temperature to prevent condensation and corrosion
- by allowing heating flexibility with zone or whole building heating

Gas-fired, high-intensity, porous, refractory, IR radiant heaters are recommended for use in aircraft hangars if natural gas is available because of the following:

- the porous, refractory, IR burners emit heat energy primarily in the longer wavelengths (2 to 6 microns) which is within the optimum absorptance range for personnel and concrete floors and has no adverse physiological effects

- porous, refractory heaters are safe for use in aircraft hangars

- when the burners glow a dull red, a malfunctioning burner would be visually apparent by intermittent burner incandescence

However, the following disadvantages should be noted:

1. Due to the inherent nature of suspending these heaters near the ceiling of an aircraft hangar, access to these heating units is restricted for inspections and maintenance. However, these difficulties can be overcome with the installation of:

    - a wall ladder and access catwalks with safety rails

    - an electrically operated solenoid shutoff valve for each heater to isolate a malfunctioning heater from the main gas supply line

2. Natural gas may not be available at the hangar location

3. The gas-fired heaters require ventilation for elimination of the flue gases. This can be provided by the following:

    - direct exhaust vents for the flue gases for vented heaters (Figure 8)

    - exhaust fans to vent the flue gases for unvented heaters (Figure 10)

RECOMMENDATIONS

1. As an energy conservation measure, radiant heaters are recommended for heating large open-bay buildings such as aircraft hangars and warehouses (both in new construction and retrofit).

2. When installing radiant heaters near the ceiling, include catwalks with safety rails and a built-in access ladder. Though this will increase the initial installation costs, the catwalks and access ladder will reduce the cost and inconvenience of inspections and maintenance over the life cycle of the heaters while providing immediate access to these systems.

3. Incorporate a zone heating capability into the heating system. This will require more heaters for the entire structure, but it will provide the hangar's manager with the flexibility to heat only the occupied areas rather than the whole hangar.

4. Use glow coil or electronic ignition systems instead of pilot light ignition for gas-fired heaters. The elimination of pilot lights will also save energy.

5. The heaters should have centralized, electrically controlled solenoid shutoff switches to enable the hangar manager to shut off unneeded heaters. Also, a malfunctioning heater can be isolated until repaired.

6. High-intensity gas-fired IR heaters, if gas is available, are recommended over other radiant heating systems.

REFERENCES

1. DeWert, D.W. Literature review of infra-red energy produced with gas burners, American Gas Association Laboratories, Research Bulletin 83, May 1960.

2. National Fire Protection Association NFPA 409-1979, Volume 10: Aircraft hangars, 409-1979, Chapter 9, Hangar services and utilities. 470 Atlantic Avenue, Boston, Mass., 1979.

3. National Fire Protection Association. NFPA 90A-1978, Volume 9: Standard on installation of air conditioning and ventilating systems. Boston, Mass., 1978.

4. ___________. NFPA 31-1978, Volume 3: Installation of oil burning equipment. Boston, Mass., 1978.

5. ___________. NFPA 54-1974, Volume 4: national fuel gas code, Parts I and II. Boston, Mass., 1974.

6. ___________. NFPA 91-1973, Volume 9: Standard for the installation of blower and exhaust systems. Boston, Mass., 1973.

7. ___________. NFPA 70-1978, Volume 6: National electrical code, article 513, aircraft hangars. Boston, Mass., 1978.

8. DeWert, D.W. A study of infra-red energy generated by radiant gas burners, American Gas Association Laboratories, Research Bulletin 92, Nov 1962.

9. Prince, F.J. "Selection and application of overhead gas-fired infrared heating devices," ASHRAE Journal, Oct 1962, pp 62-66.

10. Hardy, James D. "Physiological effects of high intensity infrared heating," ASHRAE Journal, Nov 1962, pp 36-42.

BIBLIOGRAPHY

"How to heat hangars," Airport Services Management, Jul 1969.

Alexander, J.C., "Calculations of direct energy losses from ceiling mounted radiant heating panels to penetrated areas," Energy Engineering, Aug/Sep 1981.

ASHRAE Handbook; Systems, Chapter 19, 1981.

Papers presented at the Symposium on "Field Performance of Infrared Heating Systems" at the semiannual meeting. ASHRAE, Feb 1968.

Bailey, H.R., "An experimental comparison of energy requirements for space heating with radiant and convective systems," ASHRAE Transaction 1980, vol 86, Part 1.

Boyd, R.L., "Application and selection of electric infrared comfort heaters," ASHRAE Journal, Oct 1962, pp 57-61.

Bryan, William L., "Comparative energy requirements of radiant space heating," ASHRAE Transaction 1981, vol 87, Part 1.

"Use of gas infra-red heating," Building Operating Management, Dec 1970.

Cogan, David G., "Ocular effects of radiation," AMA Archives of Industrial Health, vol 20, Oct 1959.

Fanger, P.A., et al. "Comfort limits for heated ceilings," ASHRAE Transactions vol 86 no. 2, pp 141-156.

Gagge, A.P., and Berglund, L.G., Thermal Comfort and Radiant Heat, Third National Passive Solar Conference Proceedings, 1979.

Gagge, A.P., Rapp, G.M., and Hardy, J.D., "Mean radiant and operative temperature for high-temperature sources of radiant heat," ASHRAE Transactions 1964, vol 70, pp 419-424.

Gagge, A.P., Rapp, G.M., and Hardy, J.D., "The effective radiant field and operative temperature necessary for comfort with radiant heating, ASHRAE Transactions 1967, vol 73, pp I.2.1 - I.2.9.

Hart, Gordon H., "Heating the perimeter zone of an office building: An analytical study using the proposed ASHRAE comfort standard (55-74R)," ASHRAE Transaction 1981, vol 87, Part 2.

McNall, Jr., P.E., "Thermal comfort (thermally neutral) conditions for three levels of activity," ASHRAE Transactions 1967, vol 73 pp I.3.1 - I.3.14.

Nevens, R.G., Michaels, K.B., and Feyerherm, A.M., "The effect of floor surface temperature on comfort, Part 1, College age males," ASHRAE Transactions 1964, vol 70, pp 29-36.

"Infra-red heaters prevent moisture film on floor," Pacific Factory, Jan-Feb 1974.

Conserving energy with infrared heating. Technical Publishing Co., 1977.

Infra-red radiant process heating engineering study, Thermovation, LTD. Cleveland, Ohio, 1974.

Walker, C.A., "Control of high intensity infrared heating," ASHRAE Journal, Oct 1962, pp 66-68.

Figure 1. High-intensity porous refractor IR radiant heaters.

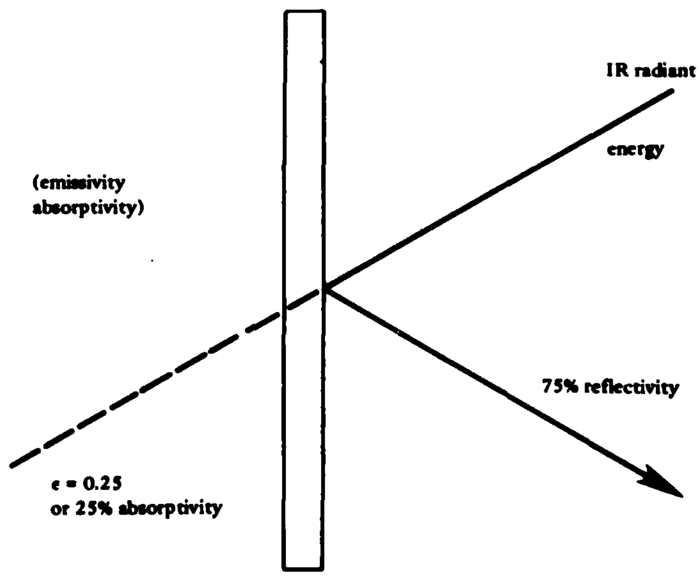


Figure 2. Reflectivity, the complement of absorptivity.

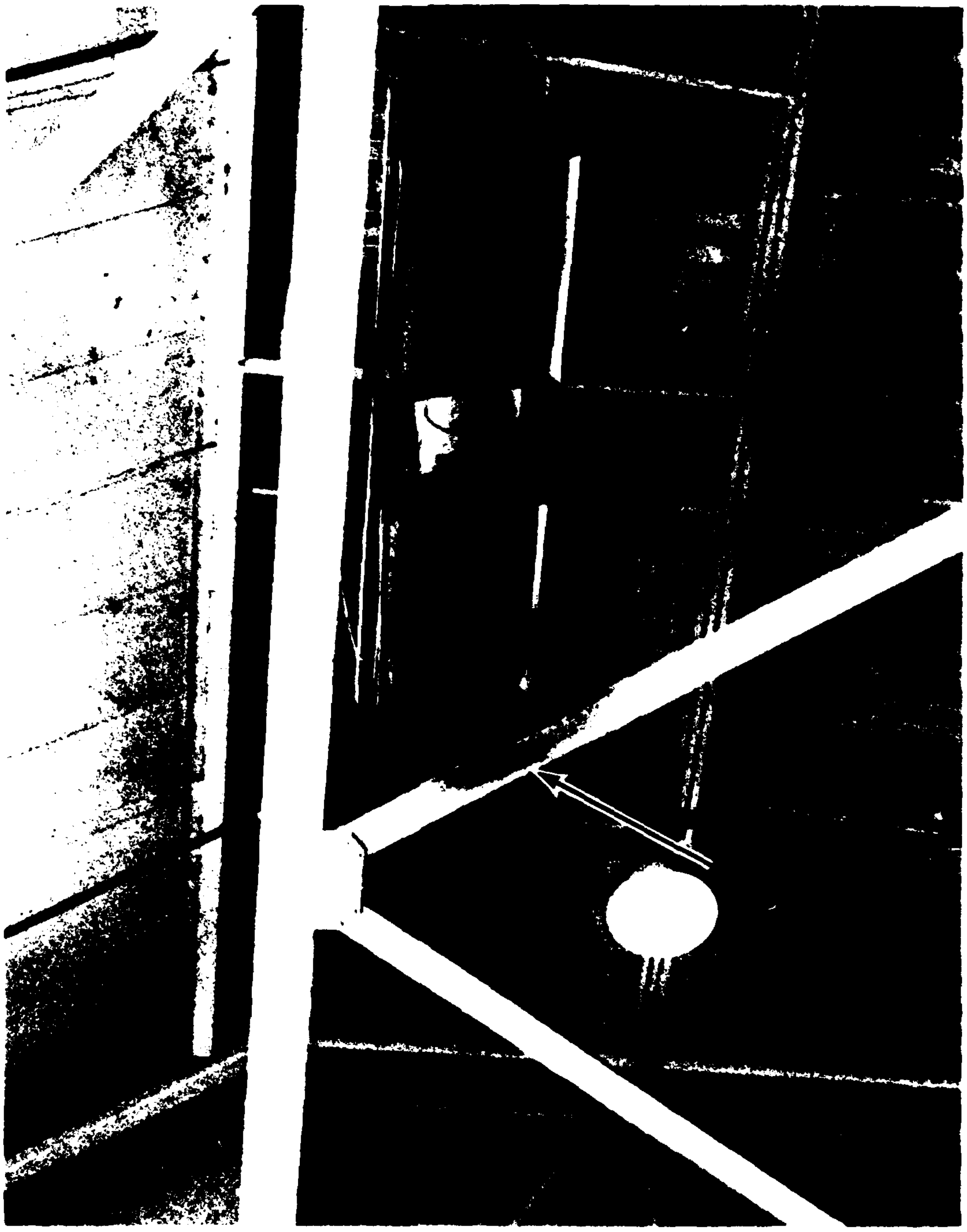


Figure 3. Damage to structural member caused by incorrectly mounted IR radiant heater.

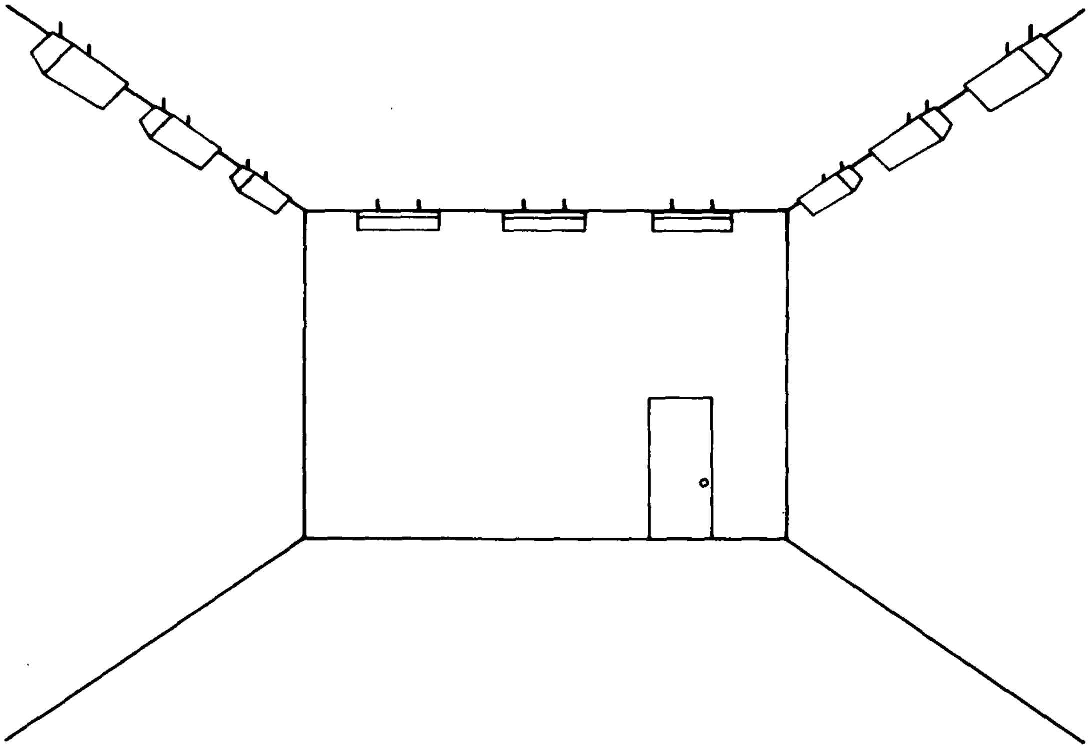


Figure 4. Perimeter arrangement of high-intensity IR radiant heaters.

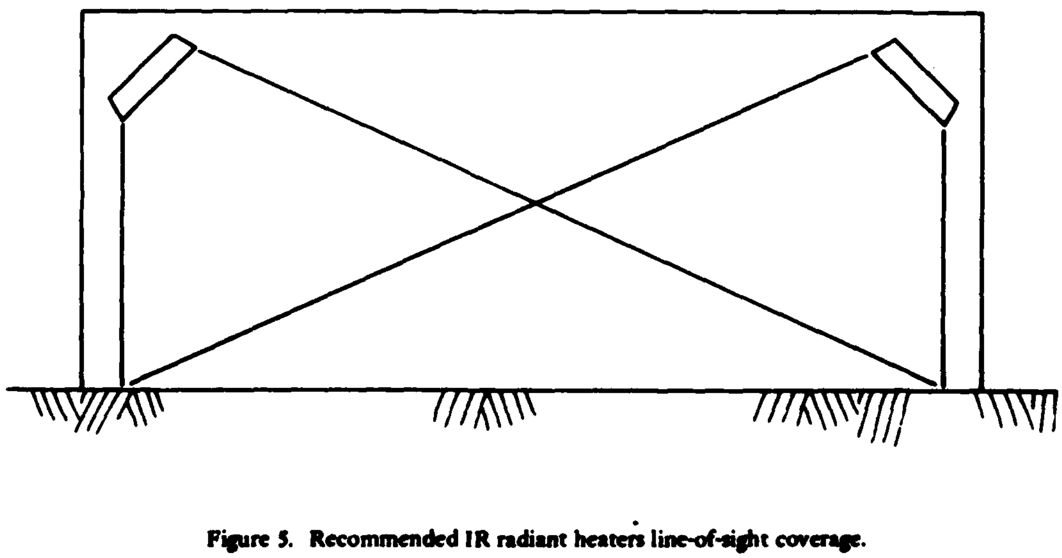


Figure 5. Recommended IR radiant heaters line-of-sight coverage.

Figure 6. Additional heaters required over hangar doors.

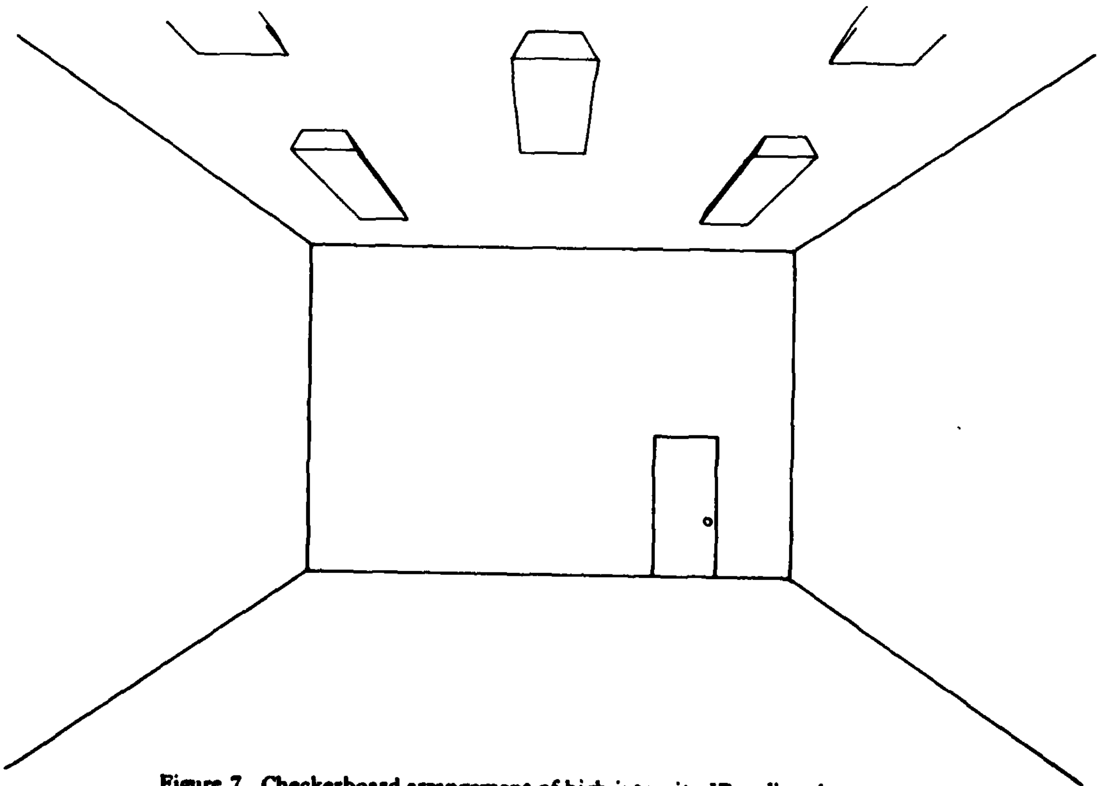


Figure 7. Checkerboard arrangement of high-intensity IR radiant heaters.

Figure 8. Venting of burners through the roof via exhaust stacks.

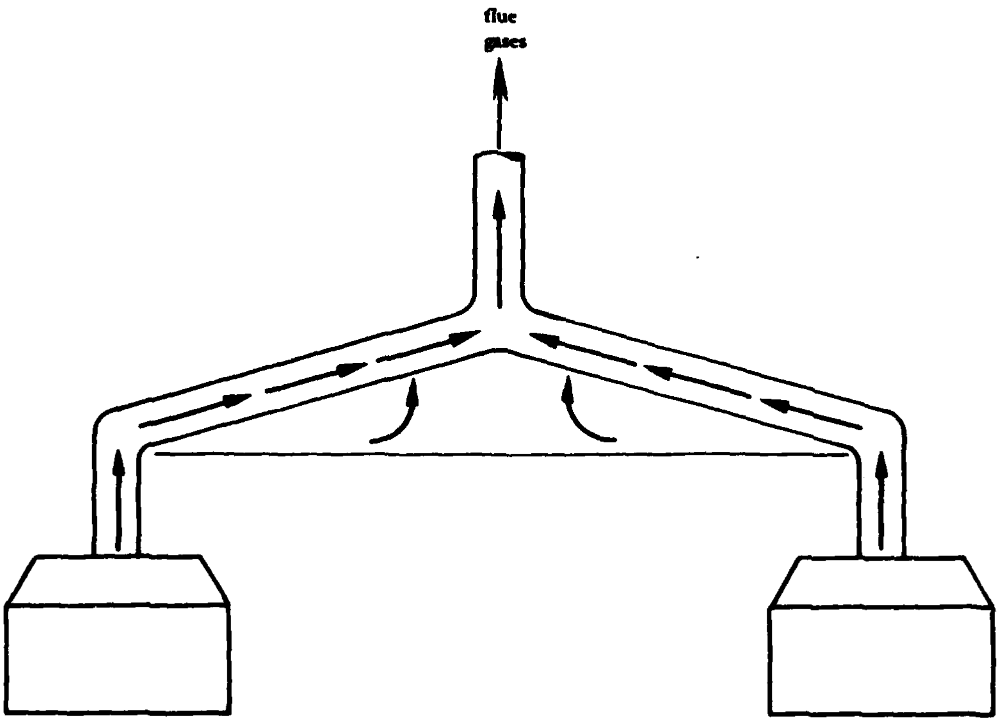
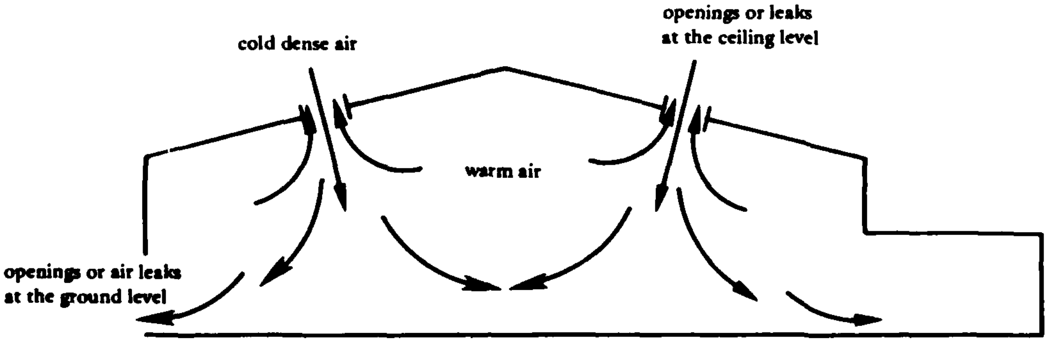


Figure 9. Incline of exhaust stacks to assure continuous rise from the IR radiant burners.

Figure 10. Exhaust fans with spring-loaded draft shutters used to vent the flue gases.



Requirements:

1. Outside air temperature < inside air temperature.
2. Ground level openings > ceiling level openings.

Figure 11. Gravity ventilation.

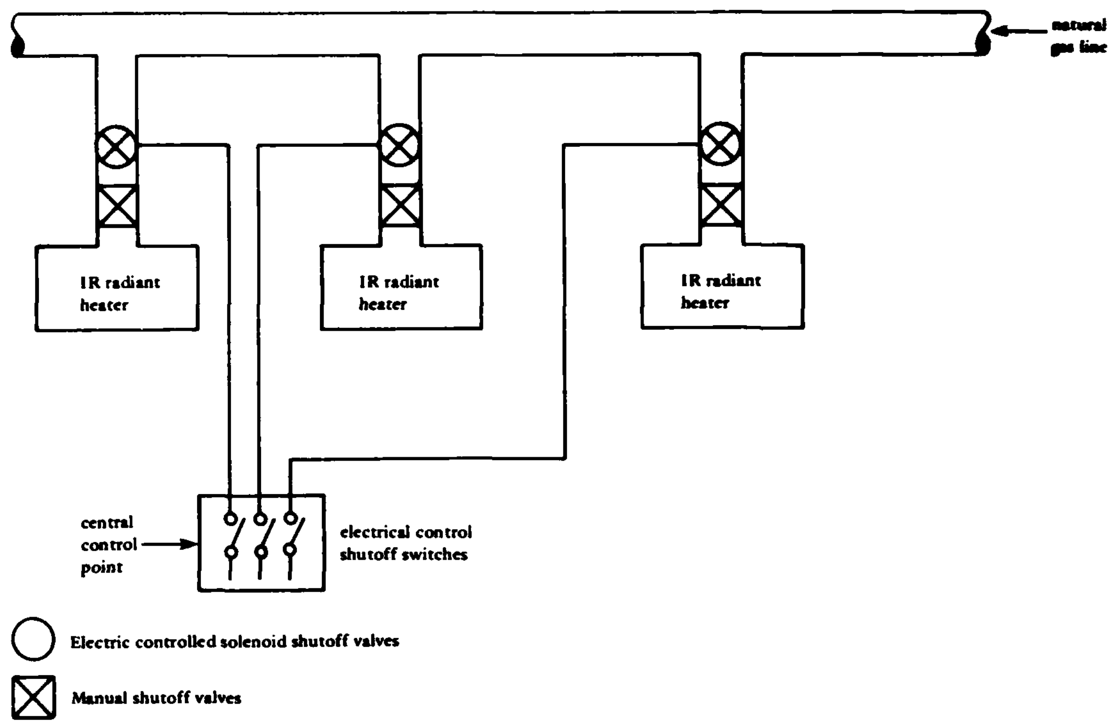


Figure 12. Individual and central shutoff valves to isolate each heater.

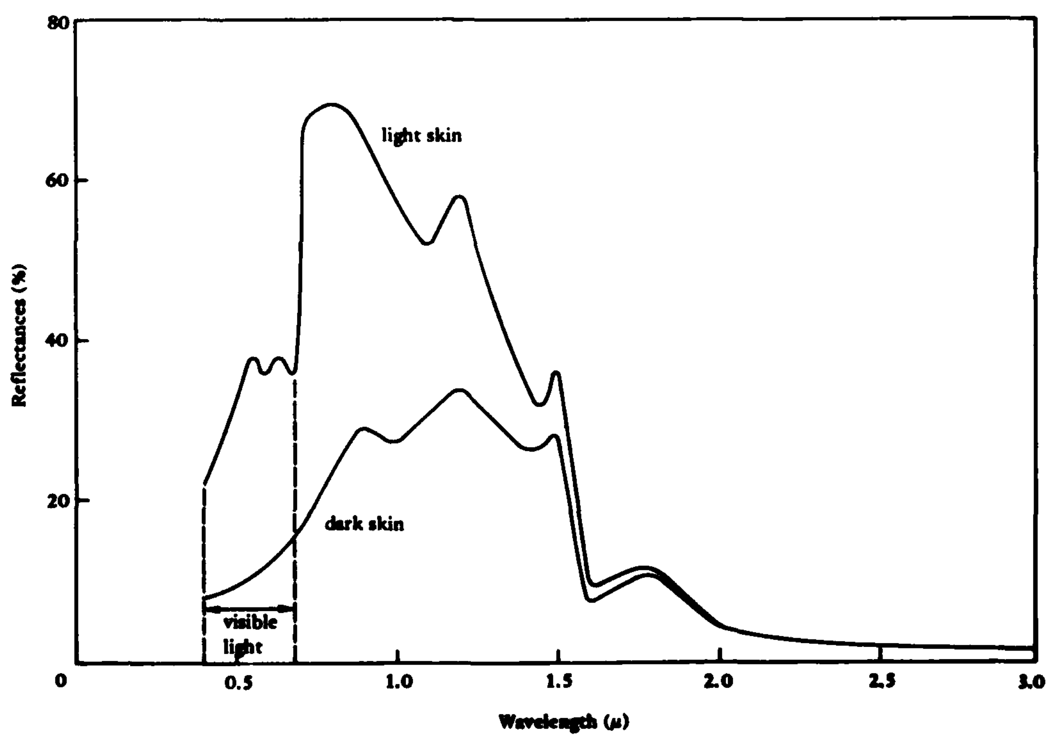


Figure 13. Average spectral reflectance values for human skin (reflectance is the complement of absorptance).

DISTRIBUTION LIST

ARMY Fal Engr, Letterkenny Army Depot, Chambersburg, PA
AFB (AFIT/LDE), Wright Patterson OH; (RDVA) AFESC/R&D Tyndall, FL; 82ABG/DEMC, Williams AZ; ABG/DEE (F. Nethers), Goodfellow AFB TX; AF Tech Office (Mgt & Ops), Tyndall, FL; CESCH, Wright-Patterson; HQ MAC/DEEE, Scott, Il; SAMSO/MNND, Norton AFB CA; Samso/Dec (Sauer) Vandenburg, CA; Stinfo Library, Offutt NE
AFESC DEB, Tyndall, FL
ARMY ARRADCOM, Dover, NJ; BMDSC-RE (H. McClellan) Huntsville AL; Contracts - Facs Engr Directorate, Fort Ord, CA; DAEN-CWE-M, Washington DC; DAEN-MPE-D Washington DC; DAEN-MPU, Washington DC; ERADCOM Tech Supp Dir. (DELSD-L) Ft. Monmouth, NJ; Natick R&D Command (Kwoh Hu) Natick MA; Tech. Ref. Div., Fort Huachuca, AZ
ARMY - CERL Library, Champaign IL
ARMY CORPS OF ENGINEERS MRD-Eng. Div., Omaha NE; Seattle Dist. Library, Seattle WA
ARMY CRREL G. Phetteplace Hanover, NH
ARMY ENGR DIST. Library, Portland OR
ARMY ENVIRON. HYGIENE AGCY HSE-EW Water Qual Eng Div Aberdeen Prov Grnd MD
ARMY MATERIALS & MECHANICS RESEARCH CENTER Dr. Lenoe, Watertown MA
ARMY MISSILE R&D CMD SCI Info Cen (DOC) Redstone Arsenal, AL
ARMY MTMC Trans Engr Agency MTT-CE, Newport News, VA
ASO PWD (ENS M W Davis), Phildadelphia, PA
BUREAU OF RECLAMATION Code 1512 (C. Selander) Denver CO
CINCLANT CIV ENGR SUPP PLANS OFFR NORFOLK, VA
CNAVRES Code 13 (Dir. Facilities) New Orleans, LA
CNM Code MAT-04, Washington, DC; Code MAT-O8E, Washington, DC; NMAT - 044, Washington DC
CNO Code NOP-964, Washington DC; Code OP 987 Washington DC; Code OP-413 Wash. DC; Code OPNAV 09B24 (H); OP987J, Washington, DC
COMFLEACT, OKINAWA PWD - Engr Div, Sasebo, Japan; PWO, Kadena, Okinawa; PWO, Sasebo, Japan
COMNAVMARIANAS Code N4, Guam
COMOCEANSYSLANT PW-FAC MGMNT Off Norfolk, VA
COMOCEANSYSPAC SCE, Pearl Harbor HI
COMSUBDEVGRUONE Operations Offr, San Diego, CA
DEFFUELSUPPCEN DFSC-OWE (Term Engrng) Alexandria, VA; DFSC-OWE, Alexandria VA
DOE Div Ocean Energy Sys Cons/Solar Energy Wash DC; INEL Tech. Lib. (Reports Section), Idaho Falls, ID
DTIC Defense Technical Info Ctr/Alexandria, VA
DTNSRDC Code 4111 (R. Gierich), Bethesda MD
DTNSRDC Code 522 (Library), Annapolis MD
ENVIRONMENTAL PROTECTION AGENCY Reg. III Library, Philadelphia PA; Reg. VIII, 8M-ASL, Denver CO
FLTCOMBATTRACENLANT PWO, Virginia Bch VA
GIDEP OIC, Corona, CA
GSA Assist Comm Des & Cnst (FAIA) D R Dibner Washington, DC ; Off of Des & Const-PCDP (D Eakin) Washington, DC
HC & RS Tech Pres. Service, Meden, Washington, DC
LIBRARY OF CONGRESS Washington, DC (Sciences & Tech Div)
MARINE CORPS BASE Code 406, Camp Lejeune, NC; Maint Off Camp Pendleton, CA; PWD - Maint. Control Div. Camp Butler, Kawasaki, Japan; PWO Camp Lejeune NC; PWO, Camp Pendleton CA; PWO, Camp S. D. Butler, Kawasaki Japan
MARINE CORPS HQS Code LFF-2, Washington DC
MCAS Facil. Engr. Div. Cherry Point NC; CO, Kaneohe Bay HI; Code S4, Quantico VA; Facs Maint Dept - Operations Div, Cherry Point; PWD - Utilities Div, Iwakuni, Japan; PWO, Iwakuni, Japan; PWO, Yuma AZ
MCDEC NSAP REP, Quantico VA
MCLB B520, Barstow CA; Maintenance Officer, Barstow, CA; PWO, Barstow CA
MCRD SCE, San Diego CA
NAF PWD - Engr Div, Atsugi, Japan; PWO, Atsugi Japan
NALF OINC, San Diego, CA
NARF Code 100, Cherry Point, NC; Code 612, Jax, FL; Code 640, Pensacola FL; SCE Norfolk, VA
NAS CO, Guantanamo Bay Cuba; Code 114, Alameda CA; Code 183 (Fac. Plan BR MGR); Code 18700, Brunswick ME; Code 18U (ENS P.J. Hickey), Corpus Christi TX; Code 8E, Patuxent Riv., MD; Dir of Engrng, PWD, Corpus Christi, TX; Dir. Util. Div., Bermuda; Grover, PWD, Patuxent River, MD; Lakehurst, NJ; Lead. Chief. Petty Offr. PW/Self Help Div, Beeville TX; PW (J. Maguire), Corpus Christi TX; PWD - Engr Div Dir, Millington, TN; PWD - Engr Div, Gtmo, Cuba; PWD - Engr Div, Oak Harbor, WA; PWD Maint. Cont. Dir., Fallon NV; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Code 1821H (Pfankuch) Miramar, SD CA; PWD, Maintenance Control Dir., Bermuda; PWO Belle Chasse, LA;

PWO Chase Field Beeville, TX; PWO Key West FL; PWO Lakehurst, NJ; PWO Sigonella Sicily; PWO Whiting Fld, Milton FL; PWO, Dallas TX; PWO, Glenview IL; PWO, Millington TN; PWO, Miramar, San Diego CA; SCE Norfolk, VA; SCE, Barbers Point HI; SCE, Cubi Point, R.P
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NAVACT PWO, London UK
NAVAEROSPREGMEDCEN SCE, Pensacola FL
NAVAIRDEVCEN Chmielewski, Warminster, PA; PWD, Engr Div Mgr, Warminster, PA
NAVAIRPROPTESTCEN CO, Trenton, NJ
NAVCOASTSYSCEN CO, Panama City FL; Code 715 (J Quirk) Panama City, FL; Library Panama City, FL; PWO Panama City, FL
NAVCOMMAREAMSTRSTA PWO, Norfolk VA; SCE Unit 1 Naples Italy; SCE, Wahiawa HI
NAVCOMMSTA Code 401 Nea Makri, Greece; PWD - Maint Control Div, Diego Garcia Is.; PWO, Exmouth, Australia; SCE, Balboa, CZ
NAVCONSTRACEN Curriculum/Instr. Stds Offr, Gulfport MS
NAVEDTRAPRODEVCEN Technical Library, Pensacola, FL
NAVEDUTRACEN Engr Dept (Code 42) Newport, RI
NAVEODTECHCEN Code 605, Indian Head MD
NAVFAC PWO, Brawdy Wales UK; PWO, Centerville Bch, Ferndale CA; PWO, Point Sur, Big Sur CA
NAVFACENGCOM Alexandria, VA; Code 03 Alexandria, VA; Code 03T (Essoglou) Alexandria, VA; Code 04B3 Alexandria, VA; Code 051A Alexandria, VA; Code 09M54, Tech Lib, Alexandria, VA; Code 100 Alexandria, VA; Code 1113, Alexandria, VA; Code 111B Alexandria, VA; code 08T Alexandria, VA
NAVFACENGCOM - CHES DIV. Code 403 Washington DC; FPO-1 Washington, DC; Library, Washington, D.C.
NAVFACENGCOM - LANT DIV. Code 111, Norfolk, VA; Code 403, Norfolk, VA; Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA; RDT&ELO 102A, Norfolk, VA
NAVFACENGCOM - NORTH DIV. Code 04 Philadelphia, PA; Code 09P Philadelphia PA
NAVCOMMUNIT CO, Cutler, East Machias, ME
NAVFACENGCOM - NORTH DIV. Code 111 Philadelphia, PA; Code 04AL, Philadelphia PA; ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. (Kyi) Code 101, Pearl Harbor, HI; CODE 09P PEARL HARBOR HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI; Library, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 403, Gaddy, Charleston, SC; Code 90, RDT&ELO, Charleston SC; Library, Charleston, SC
NAVFACENGCOM - WEST DIV. AROICC, Contracts, Twentynine Palms CA; Code 04B San Bruno, CA; Library, San Bruno, CA; O9P/20 San Bruno, CA; RDT&ELO San Bruno, CA
NAVFACENGCOM CONTRACTS AROICC, NAVSTA Brooklyn, NY; AROICC, Quantico, VA; Contracts, AROICC, Lemoore CA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC-ROICC, NAS Oceana, Virginia Beach, VA; OICC/ROICC, Balboa Panama Canal; ROICC AF Guam; ROICC Code 495 Portsmouth VA; ROICC Key West FL; ROICC MCAS El Toro; ROICC, Keflavik, Iceland; ROICC, NAS, Corpus Christi, TX; ROICC, Pacific, San Bruno CA; ROICC, Yap; ROICC-OICC-SPA, Norfolk, VA
NAVHOSP PWD - Engr Div, Beaufort, SC
NAVMAG PWD - Engr Div, Guam; SCE, Subic Bay, R.P.
NAVOCEANSYSCEN Code 4473B (Tech Lib) San Diego, CA; Code 523 (Hurley), San Diego, CA; Code 6700, San Diego, CA; Code 811 San Diego, CA
NAVORDMISTESTFAC PWD - Engr Dir, White Sands, NM
NAVORDSTA PWD - Dir, Engr Div, Indian Head, MD; PWO, Louisville KY
NAVPETOFF Code 30, Alexandria VA
NAVPETRES Director, Washington DC
NAVPHIBASE CO, ACB 2 Norfolk, VA; SCE Coronado, SD,CA
NAVREGMEDCEN PWD - Engr Div, Camp Lejeune, NC; PWO, Camp Lejeune, NC
NAVREGMEDCEN PWO, Okinawa, Japan
NAVREGMEDCEN SCE; SCE San Diego, CA; SCE, Camp Pendleton CA; SCE, Guam; SCE, Newport, RI; SCE, Oakland CA
NAVREGMEDCEN SCE, Yokosuka, Japan
NAVSCOLCECOFF C35 Port Hueneme, CA
NAVSCSOL PWO, Athens GA
NAVSEASYSCOM Code 0325, Program Mgr, Washington, DC; Code PMS 395 A 3, Washington, DC; SEA 04E (L Kess) Washington, DC
NAVSECGRUACT PWO, Adak AK; PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa
NAVSECSTA PWD - Engr Div, Wash., DC
NAVSHIPYD Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, Portsmouth, VA; Code 382.3, Pearl Harbor, HI; Code 400, Puget Sound; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; Code 453 (Util. Supr), Vallejo CA; Library, Portsmouth NH; PW Dept, Long Beach, CA; PWD (Code 420) Dir Portsmouth, VA; PWD (Code 450-HD)

Portsmouth, VA; PWD (Code 453-HD) SHPO 03, Portsmouth, VA; PWO, Bremerton, WA; PWO, Mare Is.; PWO, Puget Sound; SCE, Pearl Harbor HI
NAVSTA Adak, AK; CO, Brooklyn NY; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Dir Engr Div, PWD, Mayport FL; Dir Mech Engr 37WC93 Norfolk, VA; Engr. Dir., Rota Spain; Long Beach, CA; Maint. Cont. Div., Guantanamo Bay Cuba; PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Guam; SCE, Pearl Harbor HI; SCE, San Diego CA; SCE, Subic Bay, R.P.; Utilities Engr Off. Rota Spain
NAVSUPPACT CO, Naples, Italy; PWO Naples Italy
NAVSUPPFAC PWD - Maint. Control Div, Thurmont, MD
NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVTELCOMMCOM Code 53, Washington, DC
NAVWPNCEN Code 2636 China Lake; PWO (Code 266) China Lake, CA; ROICC (Code 702), China Lake CA
NAVWPNSTA (Clebak) Colts Neck, NJ; Code 092, Concord CA; Code 092A, Seal Beach, CA
NAVWPNSTA PW Office Yorktown, VA
NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA; PWO, Charleston, SC; PWO, Seal Beach CA
NAVWPNSUPPCEN Code 09 Crane IN
NCTC Const. Elec. School, Port Hueneme, CA
NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 430 (PW Engrng) Gulfport, MS; Code 470.2, Gulfport, MS; NEESA Code 252 (P Winters) Port Hueneme, CA; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI; PWO, Gulfport, MS
NMCB FIVE, Operations Dept; THREE, Operations Off.
NOAA (Mr. Joseph Vadus) Rockville, MD; Library Rockville, MD
NRL Code 5800 Washington, DC
NROTC J.W. Stephenson, UC, Berkeley, CA
NSC Code 54.1 Norfolk, VA
NSD SCE, Subic Bay, R.P.
NSWSES Code 0150 Port Hueneme, CA
NUSC DET Code 131 New London, CT; Code 5202 (S. Schady) New London, CT; Code EA123 (R.S. Munn), New London CT; Code SB 331 (Brown), Newport RI
OFFICE SECRETARY OF DEFENSE OASD (MRA&L) Dir. of Energy, Pentagon, Washington, DC
ONR Code 221, Arlington VA; Code 700F Arlington VA
PACMISRANFAC HI Area Bkg Sands, PWO Kekaha, Kauai, HI
PHIBCB 1 P&E, San Diego, CA
PWC ACE Office Norfolk, VA; CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; CO, Pearl Harbor HI; Code 10, Great Lakes, IL; Code 105 Oakland, CA; Code 110, Great Lakes, IL; Code 110, Oakland, CA; Code 120, Oakland CA; Code 154 (Library), Great Lakes, IL; Code 200, Great Lakes IL; Code 400, Great Lakes, IL; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 500 Norfolk, VA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 610, San Diego Ca; Code 700, Great Lakes, IL; Library, Code 120C, San Diego, CA; Library, Guam; Library, Norfolk, VA; Library, Pearl Harbor, HI; Library, Pensacola, FL; Library, Subic Bay, R.P.; Library, Yokosuka JA; Util Dept (R Pascua) Pearl Harbor, HI; Utilities Officer, Guam
SPCC PWO (Code 120) Mechanicsburg PA
TVA Smelser, Knoxville, Tenn.; Solar Group, Arnold, Knoxville, TN
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
USAF REGIONAL HOSPITAL Fairchild AFB, WA
US GEOLOGICAL SURVEY (Chas E. Smith) Minerals Mgmt Serv, Reston, VA
USCG G-MMT-4/82 (J Spencer)
USDA Forest Service Reg 3 (R. Brown) Albuquerque, NM
USNA Ch. Mech. Engr. Dept Annapolis MD; ENGRNG Div, PWD, Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Environ. Prot. R&D Prog. (J. Williams), Annapolis MD; Mech. Engr. Dept. (C. Wu), Annapolis MD; USNA/SYS ENG DEPT ANNAPOLIS MD
USS FULTON WPNS Rep. Offr (W-3) New York, NY
ARIZONA Kroelinger Tempe, AZ; State Energy Programs Off., Phoenix AZ
AUBURN UNIV. Bldg Sci Dept, Lechner, Auburn, AL
BERKELEY PW Engr Div, Harrison, Berkeley, CA
BONNEVILLE POWER ADMIN Portland OR (Energy Consrv. Off., D. Davey)
BROOKHAVEN NATL LAB M. Steinberg, Upton NY
CALIFORNIA STATE UNIVERSITY LONG BEACH, CA (CHELAPATI)
CONNECTICUT Office of Policy & Mgt, Energy, Div, Hartford, CT
CORNELL UNIVERSITY Ithaca NY (Serials Dept, Engr Lib.)
DAMES & MOORE LIBRARY LOS ANGELES, CA
DRURY COLLEGE Physics Dept, Springfield, MO

FLORIDA ATLANTIC UNIVERSITY Boca Raton, FL (McAllister)
FOREST INST. FOR OCEAN & MOUNTAIN Carson City NV (Studies - Library)
GEORGIA INSTITUTE OF TECHNOLOGY (LT R. Johnson) Atlanta, GA; Col. Arch, Benton, Atlanta, GA
HARVARD UNIV. Dept. of Architecture, Dr. Kim, Cambridge, MA
HAWAII STATE DEPT OF PLAN. & ECON DEV. Honolulu HI (Tech Info Ctr)
IOWA STATE UNIVERSITY Dept. Arch, McKrown, Ames, IA
WOODS HOLE OCEANOGRAPHIC INST. Woods Hole MA (Winget)
KEENE STATE COLLEGE Keene NH (Cunningham)
LEHIGH UNIVERSITY Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
LOUISIANA DIV NATURAL RESOURCES & ENERGY Div Of R&D, Baton Rouge, LA
MAINE OFFICE OF ENERGY RESOURCES Augusta, ME
MISSOURI ENERGY AGENCY Jefferson City MO
MIT Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.); Cambridge, MA (Harleman)
MONTANA ENERGY OFFICE Anderson, Helena, MT
NATURAL ENERGY LAB Library, Honolulu, HI
NEW HAMPSHIRE Concord NH (Governor's Council on Energy)
NEW MEXICO SOLAR ENERGY INST. Dr. Zwibel Las Cruces NM
NY CITY COMMUNITY COLLEGE BROOKLYN, NY (LIBRARY)
NYS ENERGY OFFICE Library, Albany NY
OAK RIDGE NATL LAB T. Lundy, Oak Ridge, TN
PURDUE UNIVERSITY Lafayette, IN (CE Engr. Lib)
SCRIPPS INSTITUTE OF OCEANOGRAPHY LA JOLLA, CA (ADAMS)
SEATTLE U Prof Schwaegler Seattle WA
SRI INTL Phillips, Chem Engr Lab, Menlo Park, CA
STATE UNIV. OF NEW YORK Fort Schuyler, NY (Longobardi)
STATE UNIV. OF NY AT BUFFALO School of Medicine, Buffalo, NY
TEXAS A&M UNIVERSITY W.B. Ledbetter College Station, TX
UNIVERSITY OF CALIFORNIA Energy Engineer, Davis CA; LIVERMORE, CA (LAWRENCE LIVERMORE LAB, TOKARZ); UCSF, Physical Plant, San Francisco, CA
UNIVERSITY OF DELAWARE Newark, DE (Dept of Civil Engineering, Chesson)
UNIVERSITY OF FLORIDA Dept Arch., Morgan, Gainesville, FL
UNIVERSITY OF HAWAII HONOLULU, HI (SCIENCE AND TECH. DIV.)
UNIVERSITY OF ILLINOIS (Hall) Urbana, IL; URBANA, IL (LIBRARY)
UNIVERSITY OF MASSACHUSETTS (Heronemus), ME Dept, Amherst, MA
UNIVERSITY OF NEBRASKA-LINCOLN Lincoln, NE (Ross Ice Shelf Proj.)
UNIVERSITY OF NEW HAMPSHIRE Elec. Engr. Depot, Dr. Murdoch, Durham, N.H.
UNIVERSITY OF TEXAS Inst. Marine Sci (Library), Port Arkansas TX
UNIVERSITY OF TEXAS AT AUSTIN AUSTIN, TX (THOMPSON)
UNIVERSITY OF WASHINGTON Seattle WA (E. Linger)
UNIVERSITY OF WISCONSIN Milwaukee WI (Ctr of Great Lakes Studies)
ARVID GRANT OLYMPIA, WA
ATLANTIC RICHFIELD CO. DALLAS, TX (SMITH)
BECHTEL CORP. SAN FRANCISCO, CA (PHELPS)
BROWN & ROOT Houston TX (D. Ward)
CHEMED CORP Lake Zurich IL (Dearborn Chem. Div.Lib.)
COLUMBIA GULF TRANSMISSION CO. HOUSTON, TX (ENG. LIB.)
DESIGN SERVICES Beck, Ventura, CA
DIXIE DIVING CENTER Decatur, GA
DURLACH, O'NEAL, JENKINS & ASSOC. Columbia SC
GARD INC. Dr. L. Holmes, Niles, IL
LITHONIA LIGHTING Application eng. Dept. (B. Helton), Conyers, GA 30207
MCDONNEL AIRCRAFT CO. (Fayman) Engrng Dept., St. Louis, MO
MEDERMOTT & CO. Diving Division, Harvey, LA
NEWPORT NEWS SHIPBLDG & DRYDOCK CO. Newport News VA (Tech. Lib.)
PACIFIC MARINE TECHNOLOGY (M. Wagner) Duvall, WA
PG&E Library, San Francisco, CA
PORTLAND CEMENT ASSOC. Skokie IL (Rsch & Dev Lab, Lib.)
RAYMOND INTERNATIONAL INC. E Colle Soil Tech Dept, Pennsauken, NJ
SANDIA LABORATORIES Albuquerque, NM (Vortman); Library Div., Livermore CA
SCHUPACK ASSOC SO. NORWALK, CT (SCHUPACK)
SHELL DEVELOPMENT CO. Houston TX (C. Sellars Jr.)
TEXTRON INC BUFFALO, NY (RESEARCH CENTER LIB.)
TRW SYSTEMS REDONDO BEACH, CA (DAI)
UNITED TECHNOLOGIES Windsor Locks CT (Hamilton Std Div., Library)
WARD, WOLSTENHOLD ARCHITECTS Sacramento, CA
WESTINGHOUSE ELECTRIC CORP. Annapolis MD (Oceanic Div Lib, Bryan); Library, Pittsburgh PA

WM CLAPP LABS - BATTELLE DUXBURY, MA (LIBRARY)
BRAHTZ La Jolla, CA
FISHER San Diego, Ca
KETRON, BOB Ft Worth, TX
KRUZIC, T.P. Silver Spring, MD
T.W. MERMEL Washington DC
WALTZ Livermore, CA

INSTRUCTIONS

The Naval Civil Engineering Laboratory has revised its primary distribution lists. The bottom of the label on the reverse side has several numbers listed. These numbers correspond to numbers assigned to the list of Subject Categories. Numbers on the label corresponding to those on the list indicate the subject category and type of documents you are presently receiving. If you are satisfied, throw this card away (or file it for later reference).

If you want to change what you are presently receiving:

- Delete – mark off number on bottom of label.
- Add – circle number on list.
- Remove my name from all your lists – check box on list.
- Change my address – line out incorrect line and write in correction (DO NOT REMOVE LABEL).
- Number of copies should be entered after the title of the subject categories you select.

Fold on line below and drop in the mail.

Note: Numbers on label but not listed on questionnaire are for NCEL use only, please ignore them.

Fold on line and staple.

DEPARTMENT OF THE NAVY

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300
1 IND-NCEL-2700/4 (REV. 12-73)
0930-LL-L70-0044

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DOD-316

Commanding Officer
Code L14
Naval Civil Engineering Laboratory
Port Hueneme, California 93043

DISTRIBUTION QUESTIONNAIRE

The Naval Civil Engineering Laboratory is revising its primary distribution lists.

SUBJECT CATEGORIES

1 SHORE FACILITIES
2 Construction methods and materials (including corrosion control, coatings)
3 Waterfront structures (maintenance/deterioration control)
4 Utilities (including power conditioning)
5 Explosives safety
6 Construction equipment and machinery
7 Fire prevention and control
8 Antenna technology
9 Structural analysis and design (including numerical and computer techniques)
10 Protective construction (including hardened shelters, shock and vibration studies)
11 Soil/rock mechanics
13 BEQ
14 Airfields and pavements
15 ADVANCED BASE AND AMPHIBIOUS FACILITIES
16 Base facilities (including shelters, power generation, water supplies)
17 Expedient roads/airfields/bridges
18 Amphibious operations (including breakwaters, wave forces)
19 Over-the-Beach operations (including containerization, materiel transfer, lighterage and cranes)
20 POL storage, transfer and distribution
24 POLAR ENGINEERING
24 Same as Advanced Base and Amphibious Facilities, except limited to cold-region environments
28 ENERGY/POWER GENERATION
29 Thermal conservation (thermal engineering of buildings, HVAC systems, energy loss measurement, power generation)
30 Controls and electrical conservation (electrical systems, energy monitoring and control systems)
31 Fuel flexibility (liquid fuels, coal utilization, energy from solid waste)
32 Alternate energy source (geothermal power, photovoltaic power systems, solar systems, wind systems, energy storage systems)
33 Site data and systems integration (energy resource data, energy consumption data, integrating energy systems)
34 ENVIRONMENTAL PROTECTION
35 Solid waste management
36 Hazardous/toxic materials management
37 Wastewater management and sanitary engineering
38 Oil pollution removal and recovery
39 Air pollution
40 Noise abatement
44 OCEAN ENGINEERING
45 Seafloor soils and foundations
46 Seafloor construction systems and operations (including diver and manipulator tools)
47 Undersea structures and materials
48 Anchors and moorings
49 Undersea power systems, electromechanical cables, and connectors
50 Pressure vessel facilities
51 Physical environment (including site surveying)
52 Ocean-based concrete structures
53 Hyperbaric chambers
54 Undersea cable dynamics

TYPES OF DOCUMENTS

85 Techdata Sheets
86 Technical Reports and Technical Notes
82 NCEL Guide & Updates
☐ None— remove my name
83 Table of Contents & Index to TDS
91 Physical Security


FILM
3